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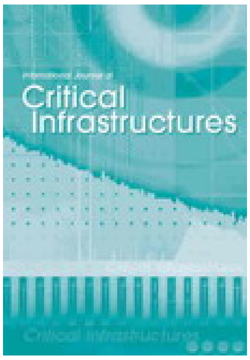

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Research on collaborative construction management of construction project based on BIM technology

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Abstract: In order to overcome the problems of high root mean square error, low monitoring accuracy and low reliability in construction project collaborative management, a new construction project collaborative management method based on BIM technology is proposed. Combined with BIM technology and collaborative management, this method establishes the network structure model of collaborative management, and expounds the evolution process of collaborative management. This method makes qualitative analysis and quantitative research on the collaborative degree of project management by combining the logistic model and order parameter principle, and completes the collaborative management of project construction based on the project organisation management system of BIM technology. The experimental results show that the root mean square of relative error is reduced by 0.84, the accuracy of monitoring is improved by 41%, and the reliability is improved by 18%, which is suitable for the collaborative management mode of current project innovation in China.

Keywords: BIM technology; construction engineering; construction management; collaborative management.

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1 Introduction

Construction industry is an important pillar industry of China's national economy. At present, there is a problem of inefficient production, which not only causes waste of resources, but also causes serious damage to the environment. With the increasing complexity and scale of engineering projects, the traditional project management mode can not adapt to the rapid development of project management at this stage. In general, it only focuses on the management of a certain stage of the project; from the perspective of the whole process of the project, due to the lack of scientific and systematic analysis, the engineering information in each stage of the whole process of the project is fragmented, forming many automation islands or information islands (Xiaohui et al.,2019; Bohnstedt and Wandahl, 2019). In the construction phase of a project, many engineering changes often occur. The reason for this phenomenon is that the project manager often only pays attention to the quality management in the construction stage, but not enough attention to the quality management in the design stage, which brings hidden dangers to the engineering construction and the project cost. Such illegal construction procedures have caused great harm to the construction projects in China. This not only reduces the project quality, delays the construction period, increases the frequency of accidents, but also increases the project cost. Some projects can not be completed after completion, resulting in long-term losses. Therefore, it is necessary to establish the project management mode, bring the interrelated and differentiated engineering factors into the dynamic environment, comprehensively manage the project as a systematic project, and define and control the project objectives (Moradi et al., 2020).

Zhang et al. (2019) proposed a collaborative management framework for hydropower project construction period based on BIM + GIS. Using BIM + GIS fusion technology, WebGL 3D graphics technology and other means, based on BIMServer and Cesium 3D GIS platform, a BIM + GIS based collaborative management system for hydropower project construction period was developed. The system provided a three-dimensional visual interactive environment with both macro and micro information for the participants of hydropower projects. By deeply combining BIM fine model with GIS large scene, the collaborative control of hydropower project management progress, cost, quality, safety and other indicators was realised, which was conducive to the scientific, refined and intelligent management in the construction stage of the hydropower project, reflecting the application value of BIM + GIS technology in the project management process of hydropower project's construction period. At present, the system has been put into use in a hydropower project, and the application effect is good. In Zhang et al. (2018) combined with P3E/C Web Service interface, the implementation process of asynchronous call was established, and the initialisation of schedule cost information model by C# secondary development of Revit was realised, which provided a benchmark model for network-based information collaboration. On this basis, the general process of schedule cost collaborative management was proposed, and the tracking analysis function of 5D schedule cost based on BIM was realised, which provided a visual information sharing and collaborative office platform for staff at different levels. Xia (2018) established a collaborative management model for construction process safety and quality based on BIM, and comprehensively used Internet, information system, intelligent equipment and other technical means. Taking the construction management application of Shenzhen Metro Project under construction as an example, based on the BIM data platform, the content of construction safety and quality of collaborative management model was further expanded. The application results of engineering practice showed that the integrated management including operators, materials, mechanical equipment, environment, safety and quality inspection as well as standard element information of process and construction method was realised, which provided an efficient, visible and controllable intelligent and interconnected information platform for the scientific management and decision-making of safety and quality in the construction process.

The research on project management in China has a history of more than 30 years, and the corresponding project management mode and method have been developed. The collaborative project management mode combines the concept of collaboration with the practice of project management, takes the owner's demand as the guidance, uses advanced information technology system, and scientifically manages the whole process of the project, so as to improve the relationship between the project subjects. Through communication and cooperation, changes and rework are reduced, to fully optimise the project quality, cost and schedule objectives, and maximise the project value. The development of BIM technology provides theoretical and technical support for the integrated management of engineering projects. The use of BIM technology can greatly promote the development of project management to high efficiency and integration. The specific performance is as follows:

1 BIM model is based on the central database and has strong intelligent parameterisation characteristics. This system can create, share and update all information of the whole project, and constantly improve and integrate.

2 Through BIM technology, the relevant target elements of each stage of the project are coordinated together to realise the process management of the whole project life cycle.

3 BIM collaborative environment has changed the existing way of information exchange and organisation cooperation between all parties. It encourages all parties of the project to strengthen information exchange and sharing by sharing benefits and risks, to realise seamless communication, and integrate project organisation and management.

The traditional management mode of engineering project has some problems, e.g., the construction process is independent and decentralised, the management content is separated from each other, the information transmission efficiency between the management subjects is low, and the cooperation and sharing ability is poor. Using BIM technology to integrate all elements of the project, this paper expounds the project management system based on BIM technology, and establishes a complete project management framework. Based on the comprehensive application of BIM, it provides reference and guidance for BIM to make full use of technology in the process of project management, and promotes the development of modern project management mode in China. This paper combines BIM technology and collaborative management to establish a BIM-based construction quality collaborative management network structure model, expounds the evolution process of construction quality collaborative management in each stage of project implementation, and combines the Logistic model and the principle of sequence parameters to coordinate project management. Perform qualitative analysis and quantitative research, and complete the collaborative management of construction projects based on the project organisation and management system based on BIM technology.

2 Collaborative construction management content of construction project based on BIM technology

With the help of BIM, we can realise the integration of multi disciplines and all participants in the process of project construction, and finally realise the integration of various data. The content of project cooperation management mainly includes project element cooperation, all parties cooperation and information cooperation (Lai et al., 2018; Liu et al., 2018). Element management is the object of management, participant management is the main body, and information management is the link between element management and participant management. The three are complementary and inseparable (Zhang et al. 2018; Wu, 2018). BIM makes the project concrete in the form of specific data. Therefore, different participants of the project can obtain different levels of project information according to their needs. Through BIM, on the one hand, it can materialise the data, that is, the shape, spatial position and overlapping relationship of buildings or components can be visualised in the form of three-dimensional model, which is convenient for the construction management operation such as technical disclosure in the later stage; on the other hand, it can also associate the operation time, construction process, construction operator information, material information, quality acceptance information and other information with components one by one, so as to truly realise the fine management and efficient management of the project.

2.1 Collaborative construction management of construction projects

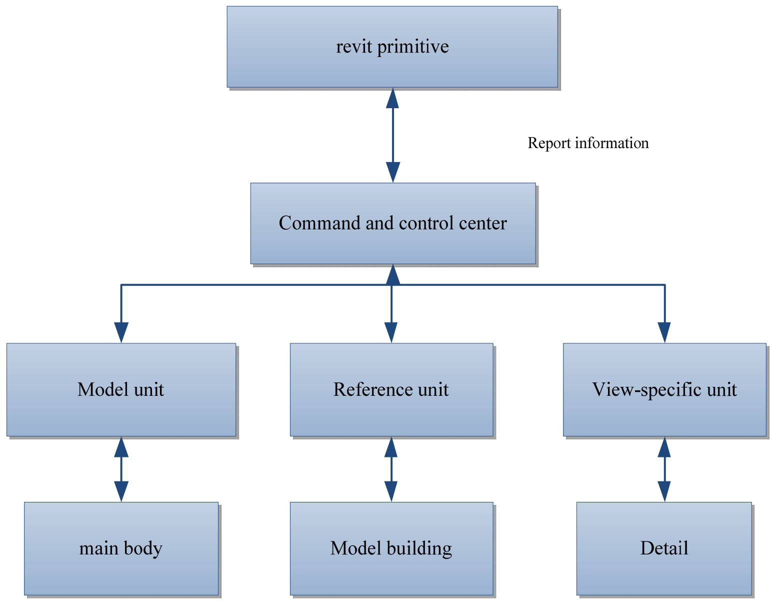
Project element management is an important aspect of collaborative management. The progress or change of each factor will directly or indirectly affect other aspects of project implementation. At the same time, each factor is related to the success of the project, and many factors are closely related, interrelated and influencing each other. This feature determines the need for collaborative management of multiple elements in project management.

BIM mode contains rich information. This paper takes view model as an example, as the basic modelling tool of BIM. Three types of primitives are often used. The classification diagram of BIM model is shown in Figure 1.

Analysis of Figure 1 shows that the model elements represent the real three-dimensional geometric model of the building, including the building body and model components. Primitive is used to define the context of a project. View specific primitives include annotation primitives and annotation primitives. Annotation primitives are two-dimensional components used to archive models and maintain a certain proportion of drawings. Annotation primitives provide a two-dimensional framework for model details in specific views (Lim et al. 2018; Chen and Qi, 2019; Xie et al., 2019).

Using BIM technology can realise the information sharing and transmission of project elements, which is conducive to the overall management of project participants. Therefore, this part mainly researches on BIM based project collaborative management from the five target elements of quality, cost, schedule, safety, and environment.

Figure 1 Diagram of BIM model classification (see online version for colours)



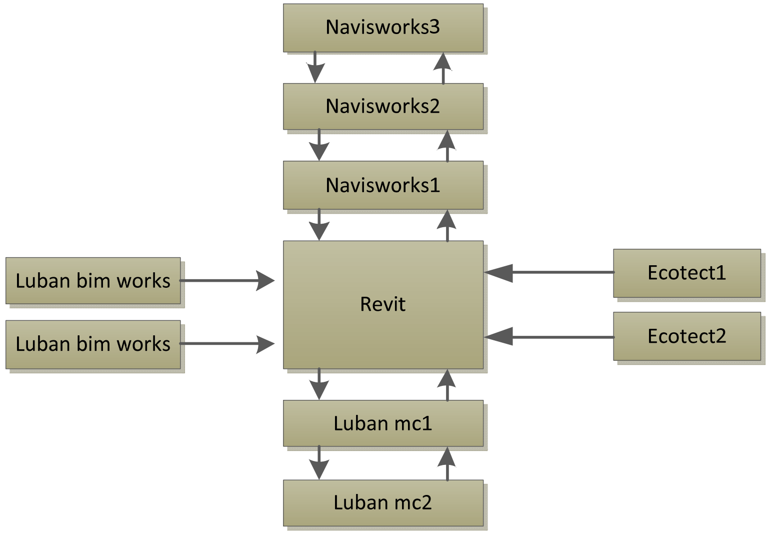
The model is a multi-dimensional building model, which contains a lot of engineering information. Based on the above classification criteria, five target analysis elements can be extracted from BIM model. The five management elements of construction project based on BIM technology are shown in Table 1.

2.2 Collaborative management of construction exchange mode of construction engineering project

Through the data exchange between BIM model and other auxiliary software, a variety of evaluation can be obtained, which provides quantitative basis for optimisation design and scheme comparison. Figure 2 shows the main exchange formats of BIM model

The advanced BIM technology is used to analyse the original two-dimensional drawings, and the three-dimensional parametric modelling method is used to uniformly express various building information in the building information model, so as to fully realise the integration and sharing of building information. In parametric collision of 3D model and collision detection, BIM series software is used to correct the model deviation, and virtual roaming technology is used to realise the comprehensive real-time detection of 3D model. On this basis, combined with RF technology and IOT sensor equipment, the quality and safety management of project progress and cost information is carried out. Finally, resource analysis, audit analysis and 5D construction simulation are carried out Zhang (2019).

Figure 2 Main interchange formats of BIM model (see online version for colours)



The whole collaborative system of BIM project improves the collaborative level of the whole project through the information and material exchange between subsystems or internal elements. However, due to the technical level, data storage and interface constraints, broadband constraints and other factors, the final collaborative level of the project will reach a limit and tend to be stable, so the evolution curve of the collaborative state of the project conforms to the characteristics of the logistic model from a macro perspective. According to the collaborative workflow among the participants of the construction project, the following assumptions are made for the collaborative state evolution model of BIM project:

Hypothesis 1 in a certain period of time, the relevant technical level, resource level, and the comprehensive quality of the participants are stable, forming constraints on project collaboration management.

Hypothesis 2 the synergy level of construction project collaboration system is directly related to the utility value of each participant.

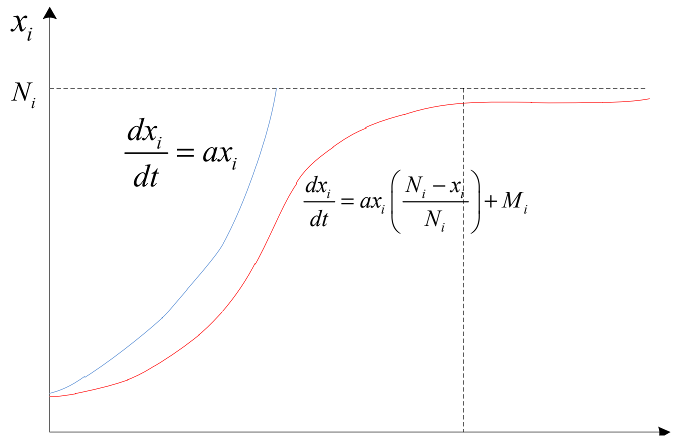
Hypothesis 3 the evolution process of the construction project collaboration system is the result of the coordination and cooperation of all the participants for the unified quality objectives.

According to the above analysis and hypothesis, the collaborative state evolution model of BIM project under the action of collaborative network is established

$$\frac{dx_i}{dt} = ax_i\left(\frac{N_i - x_i}{N_i} + \sum_{j \neq i} \frac{b_{ij}x_i}{N_j}\right) + M_i \tag{1}$$

where, x_i is the utility value of the participating member i to the project coordination level at time t; a is the inherent growth rate of the construction project collaboration system; a is the internal growth rate of the construction project collaboration system; b_{ij} is the collaborative influence coefficient among project participants; N_i is the upper limit of the cooperative state utility value of the participating member i to the collaborative system of the construction project; M_i is the random fluctuation coefficient of system evolution.

Figure 3 Evolution trajectory of bim project's collaborative state (see online version for colours)



As it can be seen from the above figure, when x_i is less than N_i, the collaboration of the system has a large space for development, which indicates that the collaborative work in the implementation process of the project is not enough. It is necessary to find out the problems in the three subsystems, give full play to the existing resource elements, and strengthen the information communication between the participants and departments. When x_i gradually approached N_i, it indicates that the resources of the project have been fully optimised. Unless there are changes in system elements such as new technical changes, the existing scheme can be implemented or the next decision can be made.

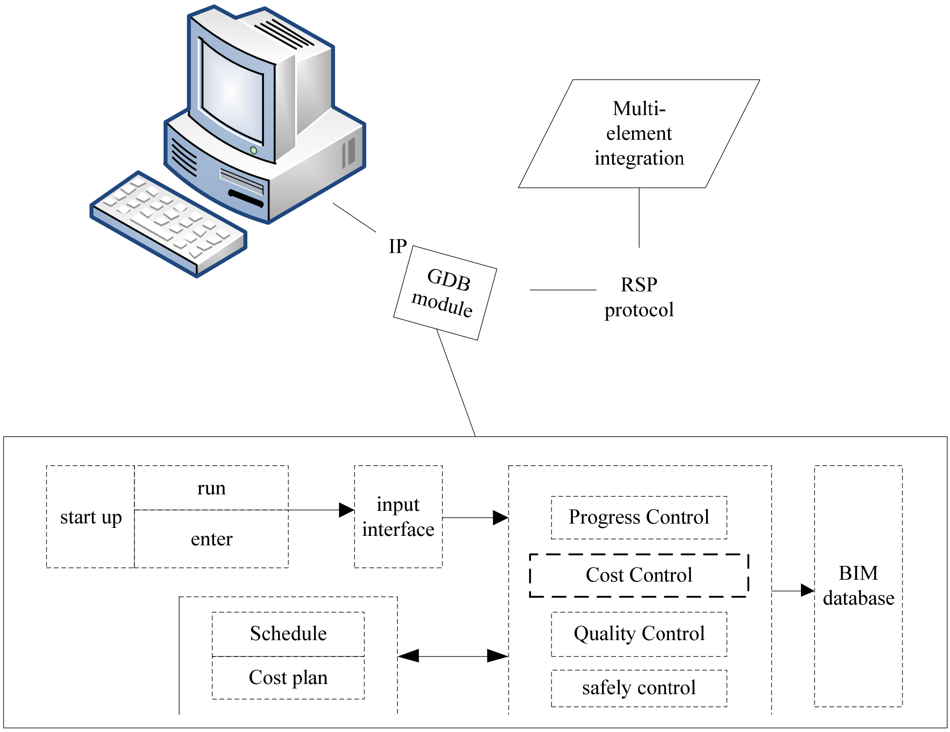
2.3 Information analysis of the whole construction process

In the whole life cycle of engineering construction, all kinds of information generated do not disappear, but continue to be used in the later stage. For example, building size, performance, and other information generated during the design phase will continue to be used in the repair and maintenance phase of the building. It is necessary to analyse the information of each stage of the project from the perspective of life cycle. Therefore, this paper analyses the data of the four stages of planning, design, construction and operation.

BIM technology mainly uses the quadratic radial basis function method to interpolate the construction quality monitoring data and establish the monitoring data. By using the distance mapping method, the physical quantity information nodes in the construction quality monitoring information are obtained, the similarity between neurons and the input weight vector under the competition level of construction quality monitoring information are obtained, and the input vector is reduced to two-dimensional plane, to effectively ensures the accuracy of dynamic monitoring visualisation algorithm.

For basic projects, management by objectives usually includes five stages: starting, planning, execution, control and implementation. The five management cores are organically combined to form a complete multi-factor integrated management system (Pengcheng et al., 2018; Moradi et al., 2020; Liu et al., 2008). Based on BIM technology and related information management tools such as Internet of things, combined with life cycle process management, a multi-factor integrated management framework based on BIM technology is constructed, as shown in Figure 4.

Figure 4 Collaborative construction management framework of construction project based on BIM technology (see online version for colours)



Planning, implementation and control are the three main links of multi factors. Among them, the planning is mainly based on the BIM technology to establish a complete resource database, so that the project manager can quickly and accurately determine the specific implementation plan of the resources invested in the BIM information management platform; through the BIM module information management platform, each element can adjust the actual deviation value of each element in real time and dynamically according to the progress control module and cost control module of BIM, and dynamically adjust the serious deviation value to control the deviation value of control results within the planning range; the control mainly considers specific deviation factors (Shi et al., 2019).

3 Collaborative construction management of construction project

The information management system platform based on BIM technology can process many engineering information such as design, construction, completion acceptance and operation, which ensures the effective flow of information and realises the information management in the whole life cycle of the project. Based on this, this paper studies the conceptual model from the data layer, information model layer and application layer of BIM information management system (Tao et al., 2019; Tang et al., 2018).

Due to the unequal development of each subsystem and the internal factors, the exchange of material resources and information data is needed to maintain the evolution of the system and promote the development of the system to a more orderly state. Therefore, with the help of the collaborative management network structure model of project quality based on BIM and collaborative system's order degree analysis, this paper quantitatively evaluates the project management collaboration degree under BIM platform, so as to guide the balanced development of subsystems in BIM project collaborative system.

In the project planning stage, BIM can help the owner to locate the project and demonstrate the project scheme. For example, the indoor and outdoor environment of the project and the site of the project are simulated and analysed; the overall scheme of the project is displayed from the aspects of visualisation effect and building virtual realisation. The application of BIM in the planning scheme is helpful to the project planning in the early stage.

In the project design stage, BIM can design the project through visualisation, and display the concept of design scheme through 3D rendering effect. At the same time, collaborative design is carried out among different disciplines to solve the design conflicts of various disciplines in a timely manner, and make the performance-based analysis of building performance from sunshine, wind energy and other aspects to help the owner control the project budget through engineering quantity statistics and cost control.

In the construction phase of the project, BIM can make the contractor better manage the project site construction through the construction schedule simulation, construction organisation simulation and construction scheme simulation, and help the owner to review the construction quantities, and finally form the completion model that can be accepted and delivered. In the operation stage of the project, the BIM model contains rich project information. The owner can manage the assets and space of the project through the BIM model, and formulate the maintenance plan to maintain the buildings regularly.

In order to determine the order degree, it is assumed that the weight of each subsystem and the corresponding order parameter component are equal, and because the order parameter components are interrelated and influence each other, the geometric average method is used to calculate the order degree of the subsystem. For each order parameter component W_{ij}, the order degree $OC\left(S_j\right)$ of each subsystem is obtained by integrating the efficacy coefficients and calculating its geometric mean：

$$OC_j\left(S_j\right)=\sqrt[m]{\Pi_{i=1}^{m}EC\left(X_{ji}\right)} \tag{2}$$

where, X_{ji} is the utility value of order parameter component W_{ij} to subsystem, $EC_j\left(X_{ji}\right)$ denotes the order degree of utility coefficient of order parameter component W_{ij} to subsystem S_j.

In this paper, the overall order degree of all subsystems in the collaborative management process is defined as the collaborative ability, and then the comprehensive collaborative ability of the collaborative management system can be obtained by geometric average of the order degree of all subsystems. The calculation formula is as follows:

$$CC = \sqrt[n]{\prod_{j=1}^{n} OC_j\left(S_j\right)} \tag{3}$$

Where S_j means that the collaborative management system of project quality is subdivided into several subsystems.

In the process of project collaborative management, each subsystem is coordinated with each other, not running independently, so when one subsystem changes, the order degree of the other subsystem may also change, which will affect the overall coordination degree of project management. Considering the coordination degree of the whole collaborative management process, the calculation results are not only related to the order degree of subsystems, but also affected by the differences between the order degrees. In this paper, the standard deviation rate D is used to eliminate the deviation of the calculation results, and the coordination degree of the project is obtained. The calculation is as follows:

$$D = \frac{\delta}{CC\left(S_j\right)} = \sqrt{\sum_{j=1}^{n} \frac{\left[OC_j\left(S_j\right) - CC\right]^2}{n-1}} / CC \tag{4}$$

$$CI = CC \cdot (1-D) = \sqrt[n]{\prod_{j=1}^{n} OC_j\left(S_j\right)} \cdot \left[1 - \sqrt{\sum_{j=1}^{n} \frac{\left[OC_j\left(S_j\right) - CC\right]^2}{n-1}} / CC\right] \tag{5}$$

where, (1-D) represents the orderly matching degree between subsystems, and CI represents the coordination degree of BIM project in the implementation management.

The BIM technology is combined with the monitoring information of residential engineering construction quality. Based on the dynamic visual monitoring technology, the whole process monitoring of residential engineering construction quality is realised by using Multi-Quadri software. The radiation basis function method is to interpolate the monitoring data field of residential building's construction quality. According to the interpolation results, the corresponding information model is established, and the physical quantities of each information point are obtained.

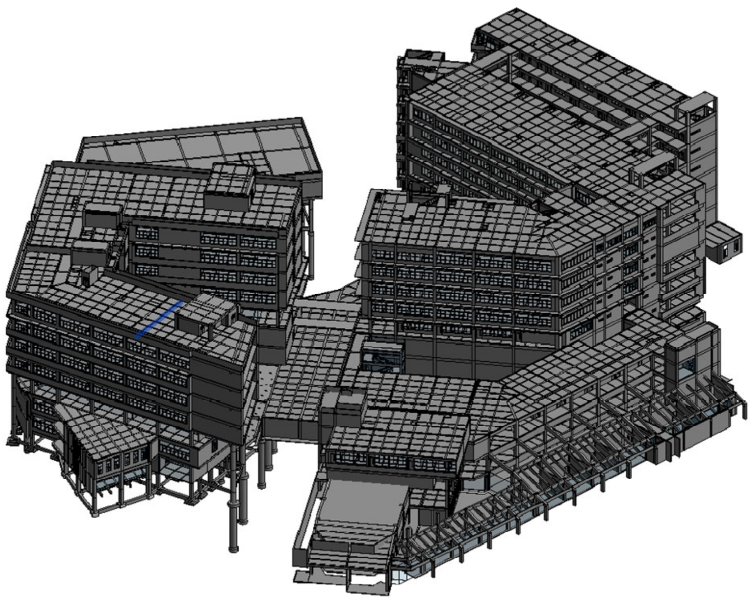
In conclusion, combined with BIM technology and collaborative management, a collaborative management network structure model of construction quality based on BIM technology is established, and the evolution process of collaborative management of construction quality in each stage of project implementation is elaborated. Combined with Logistic model and sequence parameter principle, qualitative analysis and quantitative research on project management coordination degree are carried out. According to the project organisation and management system based on BIM technology, the collaborative management of construction project is completed.

4 Experimental study

4.1 Experimental scheme

On this basis, the collaborative construction management method based on BIM technology is studied. Using Oringin 8.0 data processing and analysis software, the virtual simulation platform of construction quality inspection is established. This project is a science building of a university, with a building area of 57,322.36 m^2, covering an area of 32,828.56 m². The structure adopts cast-in-place reinforced concrete frame and frame shear wall structure system, with two lower floors and seven floors above the ground. It is a multi-functional building with laboratory nature, and integrates the functions of lecture hall, library and discussion area. Among them, the electromechanical equipment room and underground parking garage are the first floor, and the fire water collection facilities are the second floor. BIM building structure model is shown in Figure 5.

Figure 5 Structure model of bim building (see online version for colours)



In this experiment, building 1# is selected as the experimental object, and the basic situation of building 1# is shown in Table 1.

Table 1 1 Basic information of building 1#

Project	*Parameter*
Building height	40 m
Building storey	12F
Built-up area	3811.19m2
shape coefficient	0.2
South window wall ratio	0.20
Other three window to wall ratio	0.30
Exterior wall enclosure	200mm thick concrete small block, surrounded by 10 mm cement mortar
Roofing	Adopt 120mm thick reinforced concrete insulation roof 20mm1:2 cement mortar
External windows	Ordinary 8mm double-layer glass

4.2 Performance index research

1 The R, G and B gray values of pixels are used to determine the image of building's construction quality state, and it can be expressed as follows:

$$T = f(R,G,B) \tag{6}$$

where (R,G,B) is the construction image and f is the brightness coefficient of the construction quality image monitored.

The two-dimensional digital group is established, and the dynamic monitoring is implemented by using BIM technology. The formula of two-dimensional digital group is as follows:

$$T - A \times T \tag{7}$$

where A is the quality dynamic parameter of the construction building, and the value of root mean square error is usually the quantity predicted by the model or the estimated quantity observed.

Root mean square of relative error (RMS): is a measure reflecting the difference between the estimator and the estimator.

$$Accuracy(\%): \lambda_l\left(w_1,\ldots,w_k\right) = \sum_{i=1}^{K} \lambda_{li}\left(w_i\right) l_i \tag{8}$$

In the above formula, K is the number of climate zones in building sections, li is the construction quality of the building in the i-th climate zone, and w_i is the construction dynamic situation of the corresponding area of the building.

$$\text{Re}\,liability(\%): \overline{\lambda} = \frac{n}{N} \times 100\% = \sum_{i=1}^{4} \frac{n_i \times A \times e^{-as}}{N} \times 100\% \tag{9}$$

In the above formula, $\overline{\lambda}$ is the annual average early-warning rate of equipment, n is the number of early-warning scoring equipment, N is the total number of construction equipment, i is the classification of equipment status score (divided into four categories), n_i is the number of a certain type of equipment, s_i is the average value of a certain equipment score.

2 Construction monitoring error rate:

Calculation of the monitoring method based on BIM technology:

$$Y_{total} = 213633.65 + 532363.56 + 521351.23 + 422621.85 \tag{10}$$

Calculation of traditional monitoring method:

$$Y_{total} = 214632.55 + 532695.50 + 521445.65 + 422365.95 \tag{11}$$

Error P:

$$P = \left|Yt_{otal} - Y_{actual}\right| \tag{12}$$

4.3 Analysis of experimental results

The experimental results are shown in Table 2.

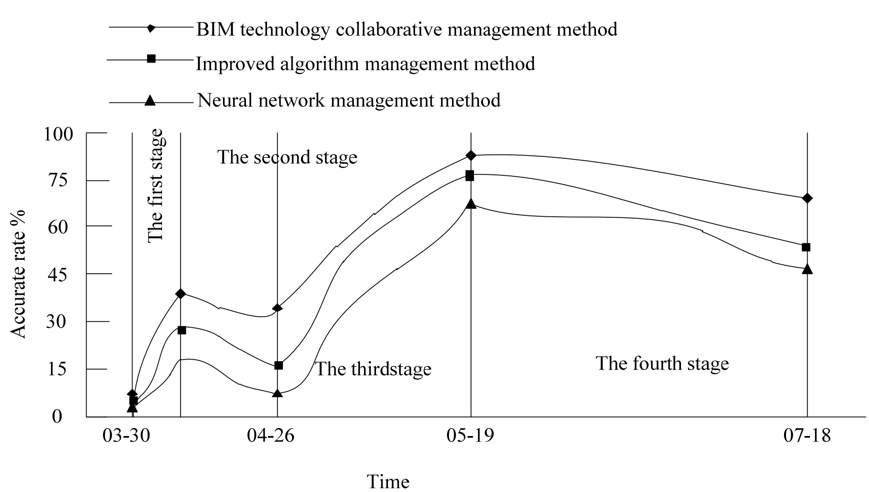
Table 2 Experimental results of dynamic monitoring of construction quality

	Collaborative management method for construction projects based on BIM technology	*Management method of Zhang et al. (2019)*	*Management method of Zhang et al. (2018)*	*Management method of Xia (2018)*
Root mean square of relative error (RMS)	0.10	1.95	2.01	1.87
Accuracy (%)	98	78	80	81
Reliability (%)	99	65	74	81

The results show that the application of BIM technology in construction quality monitoring has a good effect. The main reason is that the BIM technology mainly uses the quadratic radial basis function method to interpolate the construction quality monitoring data and establish the monitoring data. Using the distance mapping method, the physical quantity information nodes in the construction quality monitoring information are obtained, the similarity between neurons and the input weight vector under the competition level of construction quality monitoring information are obtained. The input vector is reduced to two-dimensional plane, which effectively ensures the accuracy of dynamic monitoring visualisation algorithm.

The improved algorithm based on BP neural network, the traditional visual dynamic monitoring method and the proposed collaborative management method of construction project based on BIM technology are used to carry out dynamic monitoring experiments on construction quality respectively. The error rate and monitoring effect of visual dynamic monitoring of construction quality are compared in different experimental time, and the comparison results are as follows:

Figure 6 Comparison of error rate in construction monitoring



The results of the above figure can show that the collaborative construction management method of construction project based on BIM technology can reflect the construction quality from multiple angles and ensure the stability of construction quality. The results show that the collaborative construction management method based on BIM technology has high monitoring accuracy and strong robustness. The main reason is that the proposed method uses BIM technology to integrate various elements of the project, describes the project management system based on BIM technology, establishes a complete project management framework, and improves the management quality.

5 Conclusions

Aiming at the problem that the traditional collaborative management algorithm has large errors in the project quality monitoring, a collaborative management method for construction project based on BIM technology is proposed. The BIM is fused with the monitoring information of engineering quality, and the multi quadratic radial basis function method is adopted. Using interpolation calculation method, the monitoring information model of construction quality is established, and the physical quantities of nodes are obtained. The distance mapping method is introduced to obtain the quality monitoring results. The dynamic monitoring of residential building quality is realised by the similarity between neuron in competition layer and its weight vector of input mode. The experimental results show that: compared with the traditional method, the root mean square of relative error of the proposed method is reduced by 0.84; the monitoring accuracy is improved by 41%; and the reliability is improved by 18%.

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